DETERMINING THE EFFICIENCY OF LOW-INTENSITY LASER RADIATION EXPOSURE WITH A WAVELENGTH OF 445 NM APPLIIED TO THE GINGIVAL AREA ACCORDING TO THE DATA FROM LASER DOPPLER FLOWMETRY

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ABSTRACT

BACKGROUND: *Currently, the list of diode semiconductor lasers in surgical dental practice is expanded due to the development of the blue laser. The topical issue is the evaluation of the effects of laser radiation with a wavelength of 445 nm on the microcirculation of oral cavity mucosa.* ***AIM:*** *to assess the effects of 445 nm laser radiation with a 0.1 Watt power on the microcirculation and the lymphatic flow in the gingival area using the method of laser Doppler flowmetry.* ***METHODS:*** *The efficiency of laser radiation with a wavelength of 445 nm in the gingival area was determined by the data from laser Doppler flowmetry. Dynamic changes of the basal circulation and basal lymphatic flow in the area of the attached keratinized gingiva in the teeth of the mandible were evaluated in healthy volunteers: the numerical values obtained for the microcirculation were measured along with its variability and the coefficient of variation before and after laser therapy. Statistical analysis and visualization of the obtained data were performed using the R 4.4.2 statistical calculations medium.* ***RESULTS:*** *In a total of 20 volunteers, the method of laser Doppler flowmetry has shown a significant increase of the microcirculation values in the gingival tissues upon the exposure of the laser radiation with a wavelength of 445 nm to the gingiva (gum).* ***CONCLUSION:*** *An increase of the circulation rates in the gingival tissues upon the exposure of the low-intensity laser radiation with a wavelength of 445 nm indicates the presence of a therapeutic effect caused by the blue laser. The procedures of preventing the diseases of the parodontal tissues are recommended to be supplemented by photobiomodulation with using the blue laser technology at a power of 0.1 W.*

Keywords: *microcirculation; laser Doppler flowmetry; blue laser; low-level laser irradiation; photobiomodulation.*

For citation:
Romanenko NV, Tulskikh EV, Kirsanova NM, Tarasenko SV. Determining the efficiency of low-intensity laser radiation exposure with a wavelength of 445 nm appliied to the gingival area according to the data from laser doppler flowmetry. *Journal of Clinical Practice*. 2025;16(1):38–46. doi: https://doi.org/10.17816/clinpract677229

Submitted 16.03.2025 Accepted 26.03.2025 Published online 26.03.2025

BACKGROUND

In modern dental practice and in the treatment of inflammatory or inflammatory-destructive diseases of the parodontal tissues, the low-intensity laser radiation (or Low Level Laser Therapy (LLLT)) of red or infrared spectrum is widely used [1–3]. LLLT provides a biostimulating, anti-inflammatory, analgesic and regenerative effect in the parodontal tissues [4, 5]. The mechanism of action of LLLT is related to the photochemical reactions taking place in the cells under the effects of laser radiation. The absorption of light by the chromophores leads to an activation of the cellular enzymes, to an increased synthesis of adenosinetriphosphate and to an improvement in the oxygenation of tissues [6, 7].

The results of laser Doppler flowmetry (LDF) indicate an improvement of the microcirculation in the mucosal membrane of the papillary and marginal gingiva, an increase of the capillary circulation and a growth of the vasomotor activity in the vessels when the conventional scheme of parodontal therapy is complemented by the use of laser radiation with a wavelength of 632.8 nm, 650 nm, 810 nm, 850 nm, 890 nm or 980 nm [1, 8–11]. The normalization of local circulation promotes to the dehydration of tissues and to the decreased severity of swelling. All of these factors contribute to general increase of trophic processes in the gingival tissues [3, 12].

Currently, the list of diode semiconductor lasers available for use in dental practice is extended by the inclusion of the medical blue laser with a radiation

https://doi.org/10.17816/clinpract677229
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journal of clinical practice ISSN 2220-3095 2025 Vol 16 № 1

ОПРЕДЕЛЕНИЕ ЭФФЕКТИВНОСТИ ВОЗДЕЙСТВИЯ НИЗКОИНТЕНСИВНЫМ ЛАЗЕРНЫМ ИЗЛУЧЕНИЕМ ДЛИНОЙ ВОЛНЫ 445 НМ НА ОБЛАСТЬ ДЕСНЫ ПО ДАННЫМ ЛАЗЕРНОЙ ДОППЛЕРОВСКОЙ ФЛОУМЕТРИИ

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АННОТАЦИЯ

Обоснование. *В настоящее время перечень диодных полупроводниковых лазеров для хирургической стоматологической практики расширен благодаря появлению медицинского синего лазера. Актуальным представляется изучение влияния лазерного излучения длиной волны 445 нм на микроциркуляцию слизистой оболочки полости рта.* ***Цель исследования*** *— изучить влияние лазерного излучения длиной волны 445 нм при мощности 0,1 Вт на микроциркуляцию и лимфоток в области десны методом лазерной допплеровской флоуметрии.* ***Методы.*** *Эффективность воздействия лазерным излучением длиной волны 445 нм на область десны установлена по данным лазерной допплеровской флоуметрии. Изучена динамика базального кровотока и базального лимфотока в области прикреплённой кератинизированной десны зубов нижней челюсти: определены числовые значения показателя микроциркуляции, величины его изменчивости и коэффициента вариации до и после лазерной терапии. Статистический анализ и визуализация полученных данных проведены с использованием среды для статистических вычислений R 4.4.2.* ***Результаты.*** *У 20 добровольцев методом лазерной допплеровской флоуметрии выявлено достоверное увеличение показателя микроциркуляции в области тканей десны при воздействии лазерным излучением длиной волны 445 нм на область десны.* ***Заключение.*** *Увеличение скорости кровотока в тканях десны при воздействии низкоинтенсивным лазерным излучением длиной волны 445 нм указывает на наличие у синего лазера терапевтического эффекта. В профилактические мероприятия заболеваний тканей пародонта рекомендуется включать процедуры фотобиомодуляции с применением технологии синего лазера мощностью 0,1 Вт.*

Ключевые слова: *микроциркуляция; лазерная допплеровская флоуметрия; синий лазер; низкоинтенсивное лазерное излучение; фотобиомодуляция.*

Для цитирования:

Романенко Н.В., Тульских Е.В., Кирсанова Н.М., Тарасенко С.В. Определение эффективности воздействия низкоинтенсивным лазерным излучением длиной волны 445 нм на область десны по данным лазерной допплеровской флоуметрии. *Клиническая практика.* 2025;16(1):38–46. doi: https://doi.org/10.17816/clinpract677229

Поступила 16.03.2025 Принята 26.03.2025 Опубликована online 26.03.2025

wavelength of 445±40 nm. All over the world, the manufacturers of blue lasers claim this technology as being the best for surgical preparation of the soft tissues, for the radiation with a wavelength of 445±40 nm is to a greater extent absorbed by hemoglobin, oxyhemoglobin and melanin comparing to the laser radiation of the infrared spectrum [13, 14]. In clinical practice, dental lasers of the infrared range are used both for laser surgery and for laser therapy. The topical issue is the capabilities of using laser radiation with a wavelength of 445 nm for LLLT of the mucosa in the oral cavity with a perspective of an addition of this manipulation into the set of therapeutic procedures used in cases of inflammatory diseases of the parodontal tissues.

Aim: to evaluate the effect of laser radiation with a wavelength 445 nm and with a power of 0.1 Watt on the microcirculation and lymphatic flow in the gingival area by means of using the method of laser Doppler flowmetry.

METHODS

Research design

In order to detect the signs of the 445 nm wavelength low-intensity laser radiation affecting the microcirculation in the parodontium, we have arranged an observational prospective interventional non-randomized and non-controlled research. When compiling the design of the clinical research, the PICO method was used (table 1).

Conformity criteria

Inclusion criteria: age from 18 years and older; patients of female and male gender; presence of healthy parodontium; an established diagnosis of "Chronic catarrhal gingivitis"; the presence of written voluntary informed consent from the patient for the participation in the research.

Non-inclusion criteria: age under 18 years; pregnancy, breast-feeding; intake of antiaggregants or anticoagulants by a patient; established diagnosis of "Parodontitis"; presence of a pernicious habit of smoking; periodic or constant intake of narcotic medications; oral breathing type; past medical history of concomitant diseases, affecting the system of peripheral blood supply (diabetes mellitus, arterial hypertension, metabolic syndrome); abnormal development of the facial skeleton (small roof of the atrium of the oral cavity, insufficient height of the alveolar margin of the mandible, dense location of the teeth in the anterior group at the mandible, high attachment of the mentalis muscles); myofunctional disorders (increased tone of the mentalis muscles); presence of orthodontic constructions in the oral cavity.

Exclusion criteria: the inefficiency of the diagnostic procedure due to unforeseen circumstances (for example, allergy to laser radiation).

Research facilities

The clinical research was carried out at the Department of Surgical Dentistry of the Institute of Dentistry named after E.V. Borovsky under the Federal State Autonomous Educational Institution of Higher Education "I.M. Sechenov First Moscow State Medical University" of the Ministry of Health of Russia.

Research Duration

The clinical research work was including 20 volunteers and it was carried out during the period of 2023–2024.

Medical Procedure Description

For the purpose of defining the possibilities and the practicability of using laser radiation with a wavelength of 445 nm as the energy source for laser therapy and for photobiomodulation of parodontal tissues, we have measured the parameters of microcirculation of blood and lymph in the oral cavity mucosa upon the exposure to low-intensity laser radiation in the gingival area (manipulation code A22.07.008).

The clinical research procedures were carried out in the morning, at daylight hours, with the patient positioned seated in the dental chair with the back support at an angle of 100 degrees, the patient's head positioned on the head rest. The holder of the diagnostic probe of the "LAZMA-D" analyzer was positioned on the mucosa in the zone of the attached keratinized gingiva of teeth 4.2–4.3 on the vestibular side (Fig. 1). The examination zone was selected using the method of convenient judgment-based sample. For the purpose of ruling out the artifacts when recording the perfusion, we have used the standard system consisting of a support stand and the optical fiber clamp.

The microcirculation of blood and lymph was estimated according to the data obtained by LDF, which was arranged before the LLLT being applied to the gingival area (for obtaining the control values) and in 25 minutes after its completion — for detecting the therapeutic effect. The duration of each measurement was 120 seconds.

Table 1

Flow-chart of the research design

Parameters	Designation of the symbol in this research
P	Patients (volunteers) with healthy parodontium
I	Intervention — LLLT exposure with a wavelength of 445 nm to the gingival area
C	Comparison of the results obtained using laser Doppler flowmetry before and after the LLLT exposure at a wavelength of 445 nm applied to the gingival area in volunteers
O	Outcome — determining the quality of microcirculation of blood and lymph in the examined volunteers after the LLLT procedure at a wavelength of 445 nm in the gingival area

Note. P — population, I — intervention, C — comparison, O — outcome. LLLT — low-intensity laser radiation.

https://doi.org/10.17816/clinpract677229

journal of clinical practice
ISSN 2220-3095
2025
Vol 16 № 1

The exposure of the laser radiation with a wavelength of 445 nm (ALTA BLUE, “VPG LASERONE”, Russia) was applied to the gingival area of the teeth 4.2–4.3 on the vestibular and the lingual side with a power of laser radiation being 0.1 W using the contactless method — a dynamic technique of spiral movements following the continuous wave pattern (CW) and the non-initiated fiber, lasting 30 seconds on each side (Fig. 2). The distance from the tip of the light guide to the surface of the gingiva was 4.5–5 mm. The area of exposure zone was 2 cm^2. Upon the completion of the procedure, the display of the ALTA BLUE laser equipment was showing the “total energy” value of 6 J. The power density was 3 J/cm^2.

In 25 minutes, the area of the conducted medical procedure was repeatedly examined using the same diagnostic method (LDF).

The measurement of the values of the basal circulation and lymphatic flow in the gingival area upon the exposure of laser radiation with a wavelength of 445 nm was carried out using the LDF method. The evaluation of the functional status of the microcirculation system in the gingiva was carried out using the “LAZMA ST” computerized diagnostic laser analyzer.

The “LAZMA ST” laser diagnostic analyzer (LLC “LAZMA” Research and Production Enterprise, Russia) consists of the “LAZMA-D” analyzer of peripheral circulation along with the lymphatic flow and tissue co-enzymes, also including a “LAZMA-TEST” assembly intended for temperature and electro-stimulation functional tests (Marketing authorization for medical product issued on 08.06.2017 with a number № RZN2017/5844). For the fulfillment of the objectives of the given research, we have used the “LAZMA-D” analyzer with a software version 3.0.2.384.

During the course of the LDF, such medical-biological characteristics as the peripheral circulation rate (the measure of microcirculation) and the peripheral lymphatic flow rate, were also evaluated. The value of the microcirculation rate parameter is proportional to the product of the number of red blood cells and the mean rate of its motion in the capillaries. The value of the peripheral lymphatic flow is proportional to the product of the number of scatterers in the lymphatic flow and the mean rate of its motion [15].

After a LDF session, the studied diagnostic characteristics of the basal circulation and lymphatic flow were displayed on the monitor as the colored dopplergrams and the numeric values: the microcirculation rate (M), the value of its variability (σ) and the coefficient of variation (Kv).

The coefficient of variation (Kv) determines the vasomotor activity of the microcirculation vessels in percents (%): $Kv=(\sigma/M)\times 100\%$.

Based on the obtained data, it is deemed possible to determine the status of the microcirculation in the examined area.

Statistical analysis

The research sample was determined using the Sample size formulas based on the results of similar research published earlier [16].

The statistical analysis and the visualization of the obtained data were provided using R 4.4.2 statistical calculation media (R Foundation for Statistical Computing, Vienna, Austria). For the qualitative

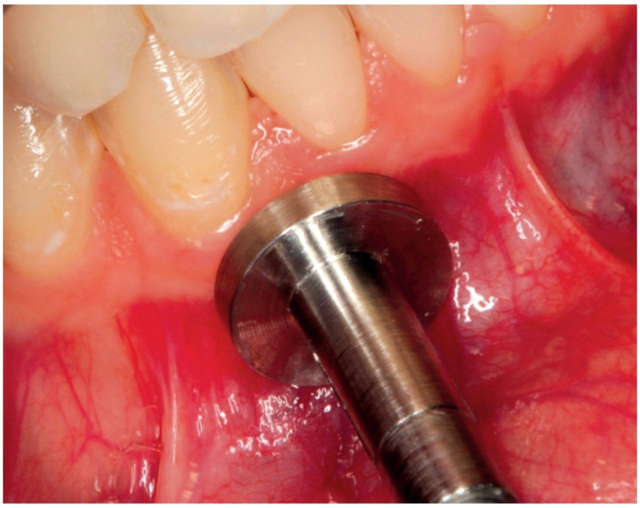

Fig. 1. The positioning of the diagnostic probe during the procedure of laser Doppler flowmetry.

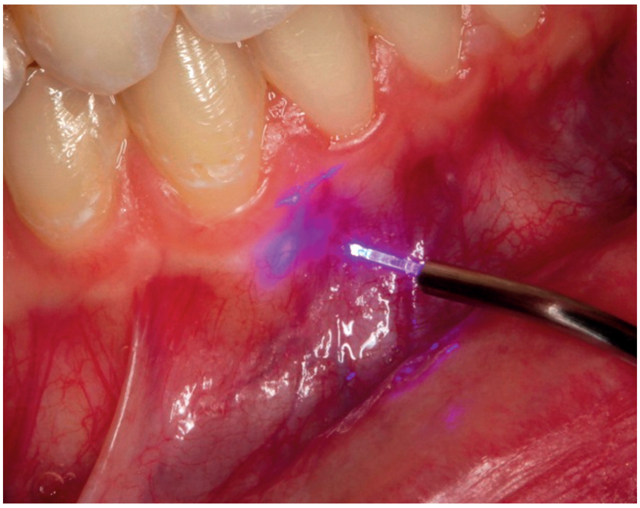

Fig. 2. The procedure of low-intensity laser radiation in the gingival area of the teeth 4.2–4.3 in a practically healthy volunteer.

parameters, the mean value, the standard deviation, the median and interquartile range were calculated; the distribution pattern was determined using the Shapiro–Wilk test.

RESULTS

Research sample (participants)

The test group included 20 volunteers — the IV- and V-year students of the Institute of Dentistry named after E.V. Borovsky, of which 10 were young men and 10 were young women aged 22–24 (mean age 22.9±0.8) years, having no pernicious habits, with no signs of inflammation in the parodontal tissues and with no past medical history of somatic diseases.

Seven to ten days prior to the examination, all the participants underwent professional oral hygiene procedures. On the day of the trial initiation, the volunteers were not taking caffeine-containing beverages. In order to participate in the research, the volunteers were visiting us 3 hours after meals and after undergoing an individual oral hygiene procedure. Within 25 minutes, the patients were informed on the purpose of the research and on the LDF method, also having their oral cavity examined with determining the dental status. This amount of time was enough for the volunteers to get a complete emotional and physiological rest. The personal data and the photos of the patients were encrypted and added to the previously compiled Google-form, which was later filled with the LDF results.

Main research outcomes

Upon the exposure of laser radiation with a wavelength of 445 nm on the gingival areas in 20 volunteers, the LDF parameters were then changing (Fig. 3). In healthy volunteers, the mean value of peripheral blood circulation (*M*) was 19.28±0.61 perf.U. The mean value of the variability of microcirculation rates (*σ*) was 3.07±0.1 perf.U. The value of the coefficient of variation (*Kv*) was calculated using the formula and it was reaching 15.92±0.66%. After the LLLT procedure, the findings included a statistically significant increase in the blood microcirculation rate (*M*) — by an average of 3.07 perf.U. (22.36±1.2; 95% CI 2.44–3.71; p <0.001). Statistically significant changes in the variability of the microcirculation value (*σ*) were not reported (p=0.319). However, after the LLLT procedure, we have found an increase in the variability of this parameter: its standard deviation has increased 6.71-fold (95% CI 4.33–10.4; p <0.001) (Fig. 3). After the LLLT procedure, we have observed an increase of the coefficient of variation (*Kv*) by an average of 1.52% (14.4±3.04; 95% CI 0.14–2.9); p=0.032). A statistically significant increase was also shown for the standard deviation of this parameter — by a factor of 4.62 (95% CI 2.98–7.15; p <0.001).

The mean value of the lymph microcirculation rate (*M*) was 0.4±0.07 perf.U. The mean value of the variability of the microcirculation rate (*σ*) was 0.12±0.04 perf.U. The value of the coefficient of variation (*Kv*) was calculated using the formula and it was reaching 30.6±7.3% (Fig. 4).

After the exposure of the 445 nm wavelength laser radiation on the gingival area, the parameter value of the lymph microcirculation rate (*M*) did not significantly change.

Undesirable phenomena

No undesirable phenomena were reported when using the LLLT procedure during the research activities.

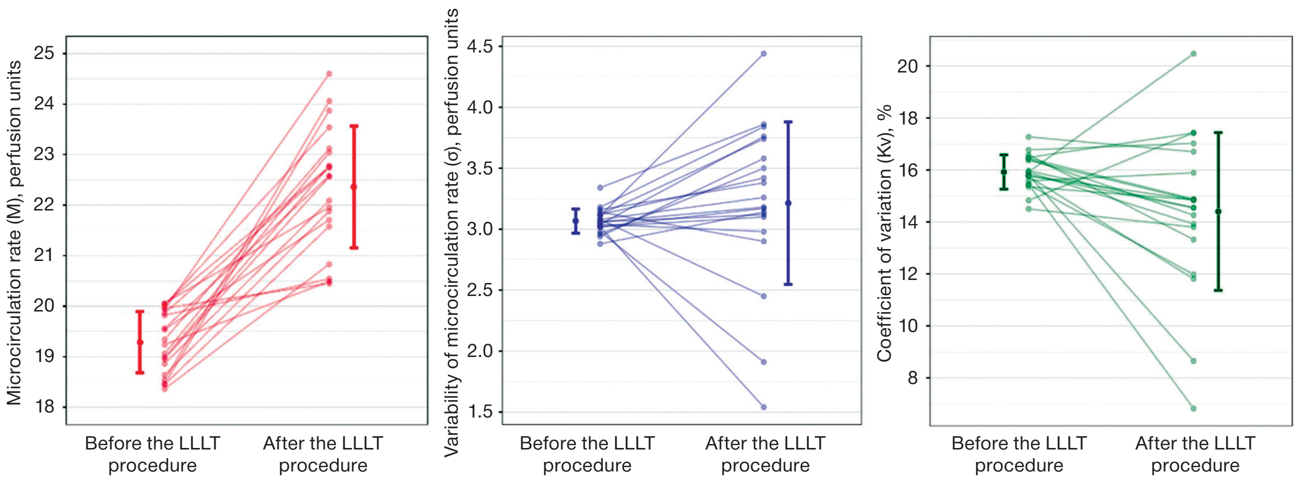

Fig. 3. Dynamic changes of the parameters of basal microvascular circulation in the gingiva, determined using the method of laser Doppler flowmetry, upon the exposure of laser radiation with a wavelength of 445 nm and with a power of 0.1 Watt.

https://doi.org/10.17816/clinpract677229

journal of clinical practice ISSN 2220-3095 2025 Vol 16 № 1

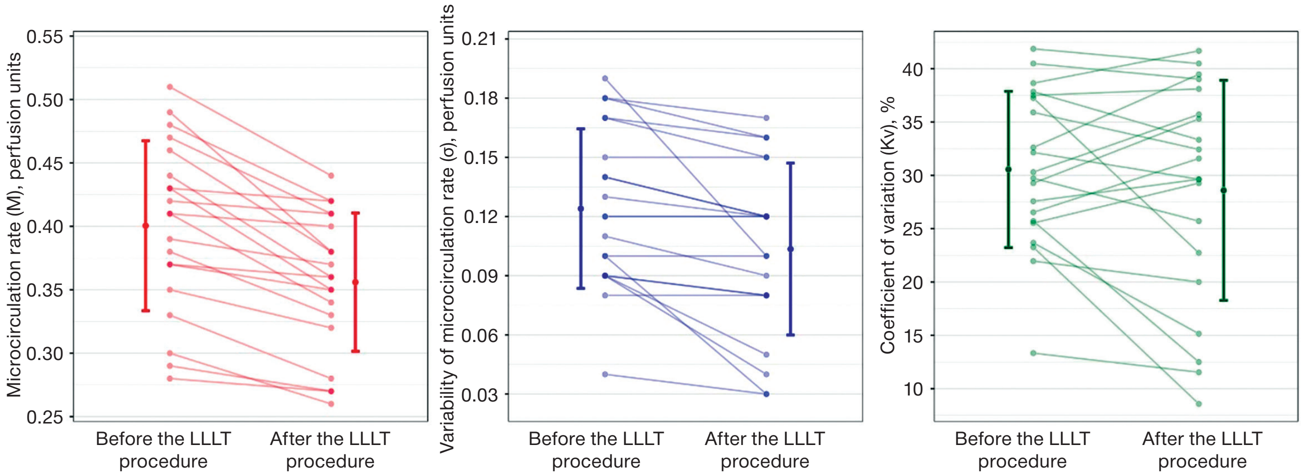

Fig. 4. Dynamic changes of the basal gingival lymphatic flow, determined using the method of laser Doppler flowmetry, upon the exposure of laser radiation with a wavelength of 445 nm with a power of 0.1 Watt.

DISCUSSION

Our research work was the first one that has assessed the exposure of the low-intensity blue laser radiation on healthy parodontal tissues. The findings included a slight but significant change in the values of basal circulation in the gingival tissues.

From the year of 2015, the worldwide dental society began using the “photobiomodulation” term to describe the LLLT procedure in the area of the healthy tissues [17]. Photobiomodulation is a potentially effective and non-invasive method of improving the microcirculation processes [10]. A contactless exposure of the laser radiation on the tissues with a small power values results in a number of physiological processes at a cellular level and at the tissue level [9].

The anti-inflammatory effect of laser radiation in cases of red and infrared range manifests at a power of 0.1–0.5 Watts and, to a greater extent, in case of minimal power values (0.1 W) [9]. It is also known that the maximal value of the physiotherapeutic exposure value — 0.5 W — is reaching the levels of the ablation mode of the blue laser. With a power of laser radiation reaching 0.7 W, the blue laser can dissect the oral cavity mucosa [18]. The practicable aspect of interest was the maximal remoteness from the power rates specific for the surgical application of the blue laser. Specifically for this reason, this clinical research was performed with selecting the laser radiation of 0.1 W for affecting the zone of attached keratinized gingiva.

The basis of the biological response in the tissues of the living organism after a low power laser radiation is the phenomenon of activating the Ca^{2+}-dependent reactions in the cells, which manifests as the increase of the redox-potential in the mitochondria, as the increase in the synthesis and the accumulation of adenosinetriphosphate, as the activation of DNA and RNA synthesis [9]. The absorption of laser energy by chromophores leads to an activation of cellular enzymes, to an increase in the parameters of oxidative metabolism parameters and to the stimulation of microcirculation along with an improvement of tissue oxygenation [19].

The increase of the circulation rates in the gingival areas after an application of laser radiation with a wavelength of 445 nm is accompanied by a decrease in the rates of lymphatic flow, which can be explained by the specific physiological features of microcirculation: upon the increase in the blood flow rates, the hydrostatic pressure in the capillaries also raises, which complicates the filtration of fluid in the interstitial space. The increase of the pressure also promotes to re-absorption of liquid from the interstitium back to the blood, decreasing the volume of fluid, accessible for the formation of the lymph. Upon the acceleration of the circulation, it shortens the time of contact between the blood and the capillary walls, which decreases the possibility of fluid diffusion into the interstitial space [15]. Similar to the findings from T.N. Safonova et al. [20], an increase of the circulation rate determines the decrease in the lymphatic flow rate and promotes to the acceleration of the oxidative processes in the gingival tissues. In our research, we have also observed the tendency to decreasing the lymphatic microcirculation rates, though not achieving the threshold of statistical significance.

In case of impairments in the functioning of the microcirculation network, there occurs the deceleration of the circulation, the changes in the shape and the number of functioning of the capillaries, with developing a venous congestion, which results in the formation of cyanosis of mucosa in the papillary and marginal gingiva [21, 22].

The exposure of laser radiation with a wavelength of 445 nm at a power of 0.1 W within 1 minute on the gingival area of a single tooth causes an increase in the circulation rate in the parodontal tissues in healthy volunteers. In the accessible literature, there is no scientific data on the effects of blue laser radiation on the microcirculation in the gingival tissues when using larger power rates. The experiments have shown that, when not following the LLLT methodical guidelines of the power not exceeding 0.5 W, heating develops in the parodontal tissues of the laboratory animals (up to 52.3°C), which is significantly higher than the threshold values (42°C) [23]. It is known that the peak of laser radiation absorption by hemoglobin corresponds to the wavelength of the blue range of the spectrum [10]. When using the laser radiation power that is close to the ablation threshold, the LLLT procedure can result in the aggregation of red blood cells and blood clotting. Based on the obtained results and on the scientifically justified facts when arranging the activities for preventing the parodontal diseases, it is recommended to undergo the photobiomodulation procedures with using the blue laser technology at a power of 0.1 W.

Laser Doppler flowmetry is an objective and non-invasive method of functional diagnostics of microcirculation in the superficial tissues, allowing for continuous registration of circulation and lymphatic flow at the real time mode [15, 24]. The main measured parameters in LDF are the dynamic changes of microcirculation and the spectral elements of the fluctuations of circulation and lymphatic flow in the tissues [15, 25]. These parameters depend on multiple physiological, pathological and physical factors, such as the gender, the age, the emotional status of the person, the presence of vascular abnormalities, the presence of metabolic diseases, the air temperature in the functional diagnostics office etc. [15, 26–29], due to which, for objectivization of the results obtained during the functional examination, we have used the preliminary preparation of the patients within 25 minutes.

A perspective aspect is the evaluation of the specific features of microcirculation in the gingival area upon the exposure of laser radiation with a wavelength of 445 nm in patients with the diagnosis of “Gingivitis and parodontitis”.

Research limitations

The limitation of the research is that it is single-center and non-randomized. Also, another fact that we count as a limitation is the absence of the aim of evaluating the additional microcirculation parameters, accessible for analysis when using the «LAZMA ST” laser diagnostic equipment.

CONCLUSION

For the first time, an information was obtained on the possibilities of clinical application of the innovative laser technology with a wavelength of 445 nm during the photobiomodulation of the parodontal tissues. The estimation of the effects of blue laser on the gingival microcirculation was undertaken with a power of laser radiation being 0.1 W. This power parameter is maximally remote from the value, in which the blue laser can provide a contactless separation of the oral cavity mucosa. The obtained results on the increase of circulation rate at laser radiation power of 0.1 W indicate the possibility of using this photobiomodulation mode in clinical practice.

ADDITIONAL INFORMATION

Author contribution. *N.V. Romanenko* — concept and study design, conducting a clinical trial, manuscript writing, statistical data processing, final scientific editing, formulation of conclusions; *E.V. Tulskikh* — participation in a clinical trial, data collection and statistical analysis; *N.M. Kirsanova* — participation in a clinical trial, data collection, literature review; *S.V. Tarasenko* — final scientific editing, general guidance. The authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

Ethics approval. The clinical trial was approved by the local ethics committee of the Federal State Autonomous Educational Institution of Higher Education “I.M. Sechenov First Moscow State Medical University” of the Ministry of Health of the Russian Federation on February 16, 2023 (LEK Protocol № 03-23 dated February 16, 2023).

Acknowledgments. The authors express their gratitude to the head of the scientific and production enterprise “LAZMA” Viktor V. Sidorov for training in working with the laser diagnostic device “LAZMA ST” and consulting.

Funding source. This study was not supported by any external sources of funding.

Competing interests. The authors declare that they have no competing interests.

https://doi.org/10.17816/clinpract677229

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https://doi.org/10.17816/clinpract677229